Top quark working group summary

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Johns Hopkins University

(for top group conveners: K. Agashe, R. Erbacher, C. Gerber and R. Schwienhorst)

Outline

- Activities of the working group
- Highlights of the meeting
- Future plans and projects

Our goals and activities

- The goal of our working group is to understand properties of top quarks, how top quarks fit into the big picture and why are they relevant for the future of the energy frontier

- Activities:

  - top quark mass (contacts: A. Mitov, M. Vos)

  - kinematics of top-like final state (contacs: M. Schulze, A. Jung, J. Shelton)

  - top quark couplings (contacts: J. Adelman, M. Baumgart, A. Garcia-Bellido, A. Loginov)

  - rare top decays (contacts: N. Craig, M. Velasco)

  - new physics in top-like events (contacts: T. Gollling, A. Ivanov, J. Hubisz, M. Perelstein)

  - top quark detection algorithms (contacts: S. Chekanov, J, Dolen, J. Pilot, R. Poeschl, B. Tweedie)

Top quark mass / Top quark kinematics

- What is the top quark mass parameter that is measured at a hadron collider?
- How precisely can the top quark mass be measured?
- How precisely should the top quark be measured? What do we learn from improving precision on the top quark mass by a factor 10?
- What is the right facility to measure the top quark mass to the required precision?

- How well kinematic distributions in processes with top quarks pair can/should be known?
- What are physics cases where a better knowledge of top quark kinematic distributions is important?
- Can improved knowledge of kinematic distributions be translated into better couplings measurements?

Top quark couplings / New physics in tops/ Rare decays

- How well the top quark couplings to electroweak gauge bosons, the gluon and the Higgs boson can be constrained at various colliders?
- How does achievable precision translate into the reach for BSM physics?

- Is there physics beyond the Standard Model which is primarily accessible through processes with top quarks?
- What are generic types of such physics and how to search for it?
- What is the role of a LC to study such physics ?

Are there decays of top quarks mediated by FCNCs? How well can they be studied at the LHC and future collider? What are the implications of observations of such decays? How well CKM matrix elements Vts and Vtd can be measured?

Tops and detectors

- What are the challenging issues for detecting top quarks at future colliders?
- Can new algorithms be developed or existing algorithms improved substantially ?
- Can top quarks become standard candles, for example for jet energy scale measurements ?
- Is their any top quark physics that is limited by proposed parameters of detectors at future colliders?

What was happening at the meeting

- This was an intense meeting !
- Two group-wide discussions about how to move forward
- Six parallel sessions
  - Top couplings theory (3 talks)
  - Top couplings measurement (5 talks)
  - New physics searches involving tops (7 talks)
  - Detecting top quarks (4 talks)
  - Kinematics of top-like final states (3 talks)
  - Top quark mass (5 talks)

Thanks to everybody who contributed !

Top couplings

Top quark couplings

- Effective operators can be used to describe modifications of the top quark couplings to the SM
- Current constraints from top quark width, W-boson helicity fractions measurements are interesting
- SM predictions for the width and helicity fractions are very precise
- Improvements in experimental measurements of top width and helicity fractions will lead to tight constraints on these higher-dimensional operators

$$\frac{\Gamma(t \to b e^+ \nu_e)}{GeV} = 0.1541 + \left[0.019 \frac{C_{\phi q}^{(3)}}{\Lambda^2} + 0.026 \frac{C_{tW}}{\Lambda^2} + 0 \frac{C_{ql}^{(3)}}{\Lambda^2}\right] \mathrm{TeV}^2$$

$$\left.\begin{array}{r} \frac{\Gamma_t}{GeV} = \Gamma_{SM} + \left[0.17 \frac{C_{\phi q}^{(3)}}{\Lambda^2} + 0.23 \frac{C_{tW}}{\Lambda^2}\right] \mathrm{TeV}^2 \\ \Gamma^*_{meas} = 2^{+0.47}_{-0.43}\,\mathrm{GeV} \\ \Gamma^{**}_{SM} = 1.33\,\mathrm{GeV} \end{array}\right\} \boxed{\frac{C_{\phi q}^{(3)}}{\Lambda^2} + 1.35 \frac{C_{tW}}{\Lambda^2} = 4^{+2.8}_{-2.5} \mathrm{TeV}^{-2}}$$

$$\frac{1}{\Gamma} \frac{d\Gamma}{d\cos\theta} = \frac{3}{8}(1+\cos\theta)^2 F_R + \frac{3}{8}(1-\cos\theta)^2 F_L + \frac{3}{4}\sin^2\theta F_0$$

$$\begin{aligned} F_0 &= \frac{m_t^2}{m_t^2 + 2m_W^2} - \frac{4\sqrt{2}\mathrm{Re}C_{tW} v^2}{\Lambda^2 V_{tb}} \frac{m_t m_W (m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2} \\ F_L &= \frac{2m_W^2}{m_t^2 + 2m_W^2} + \frac{4\sqrt{2}\mathrm{Re}C_{tW} v^2}{\Lambda^2 V_{tb}} \frac{m_t m_W (m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2} \\ F_R &= 0 \end{aligned}$$

$$\left.\begin{array}{r} F_0^{SM*} = 0.687 \pm 5 \\ F_0^{meas**} = 0.66 \pm 5 \end{array}\right\} \boxed{\frac{C_{tW}}{\Lambda^2} = 0.44 \pm 0.9 \mathrm{TeV}^{-2}}$$

C. Degrande

FB asymmetry

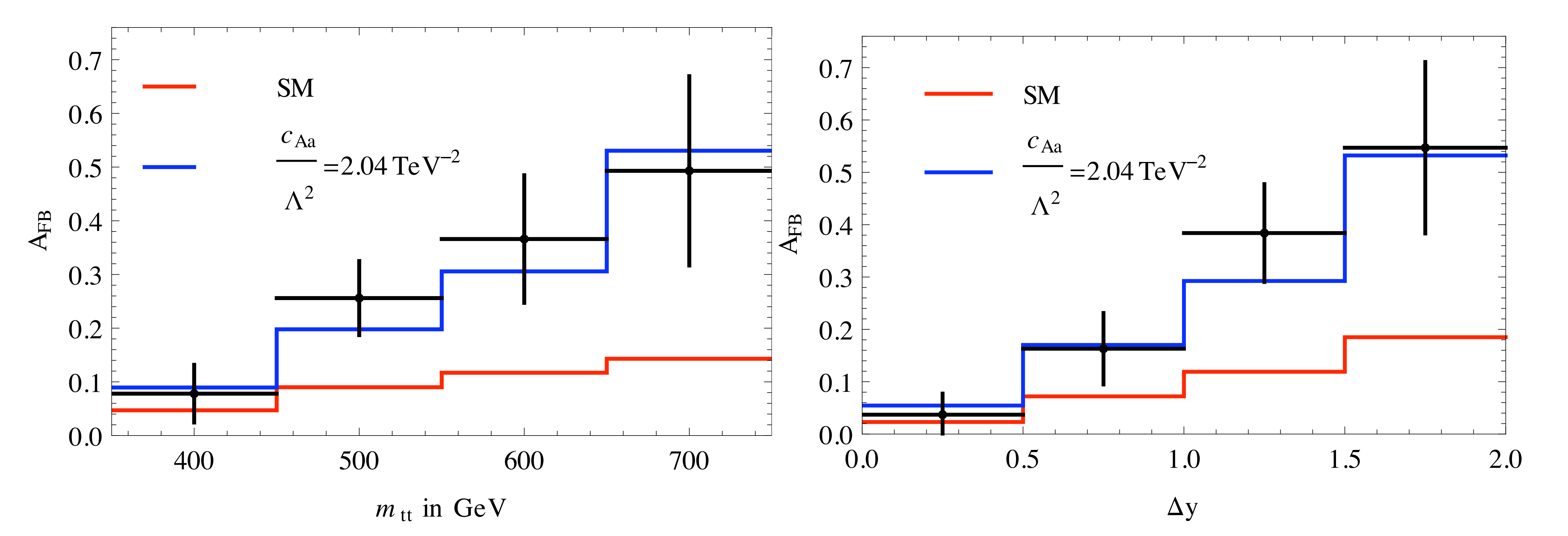
Only parameter!

$$A_{FB}^{obs} = 0.162 \pm 0.047$$

$$A_{FB}^{SM} = 0.066 \pm 0.007$$

$$c_{Aa} = c_{Ra} - c_{La}$$

$$\delta A_{FB} = 0.047^{+0.016}_{-0.011} c_{Aa} \left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2 \Rightarrow c_{Aa} \left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2 = 2.04^{+2.12}_{-1.38} \mathrm{TeV}^{-2}$$

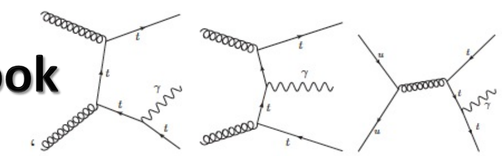


LHC Charge Asymmetry: $c_{Aa} \left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2 = -1.3^{+2.8}_{-1.3} \mathrm{TeV}^{-2}$

C. Degrande

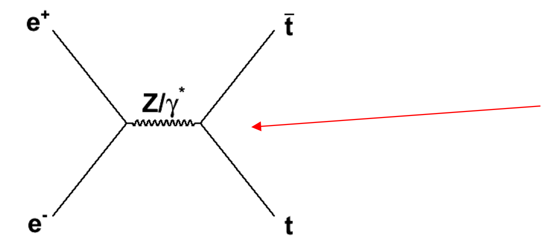
ttZ and tt+Photon couplings

ttbar + Photon: Outlook

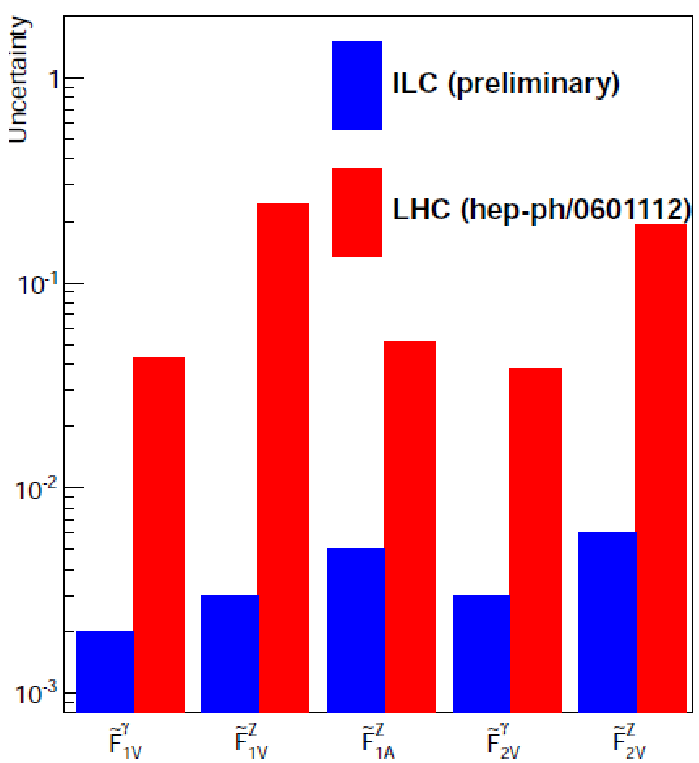


- With current 2011 / 2012 data
  - Should be able to measure ttbar + photon cross section with 5+ sigma significance (separately in 7 TeV and in 8 TeV data)
  - Can play around with ΔR (photon, X) cuts to isolate photons coming from top, **Phys.Rev. D71 (2005) 054013**
- **7** -> **14** TeV: LO cross section increases by a factor of **5** (**MadGraph,** photon p_T > **20** GeV**)**
  - **300 fb^{-1}**: few thousands events expected => can go for couplings measurement, **Phys.Rev. D71 (2005) 054013**
    - In both lepton + jets and dilepton channels
  - **3000 fb^{-1}**: differential measurements (couplings as a function of photon p_T etc)

$$\Gamma^{\mu}_{t\bar{t}(\gamma,Z)} = ie\left[\gamma^{\mu}\left[F^{\gamma,Z}_{1V} + F^{\gamma,Z}_{1A}\gamma^{5}\right] + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}\left[F^{\gamma,Z}_{2V} + F^{\gamma,Z}_{2A}\right.\right.$$

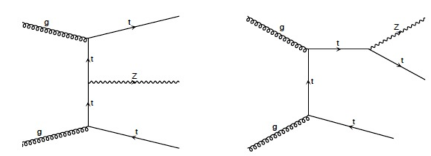


The vertex we are probing



M.Vos

ttbar + Z: Outlook



- With current 2011 / 2012 data
  - **7** -> **8** TeV: ttZ LO cross section increases by a factor of **1.4** (**MadGraph; see also talk of N.Kidonakis this morning**)
    - Stat. uncertainty will decrease by a factor of **2.5**
    - Still **limited by statistics**
    - **ttW** has a similar increase in the xsec
- **7** -> **14** TeV: LO cross section increases by a factor of **10** (**MadGraph**)
  - **300 fb^{-1}**: ttZ axial (vector) couplings can be determined with an uncertainty **45-85% (15-20%)**, **Phys.Rev. D71 (2005) 054013**
  - **3000 fb^{-1}**: a factor of **3** better

A. Loginov

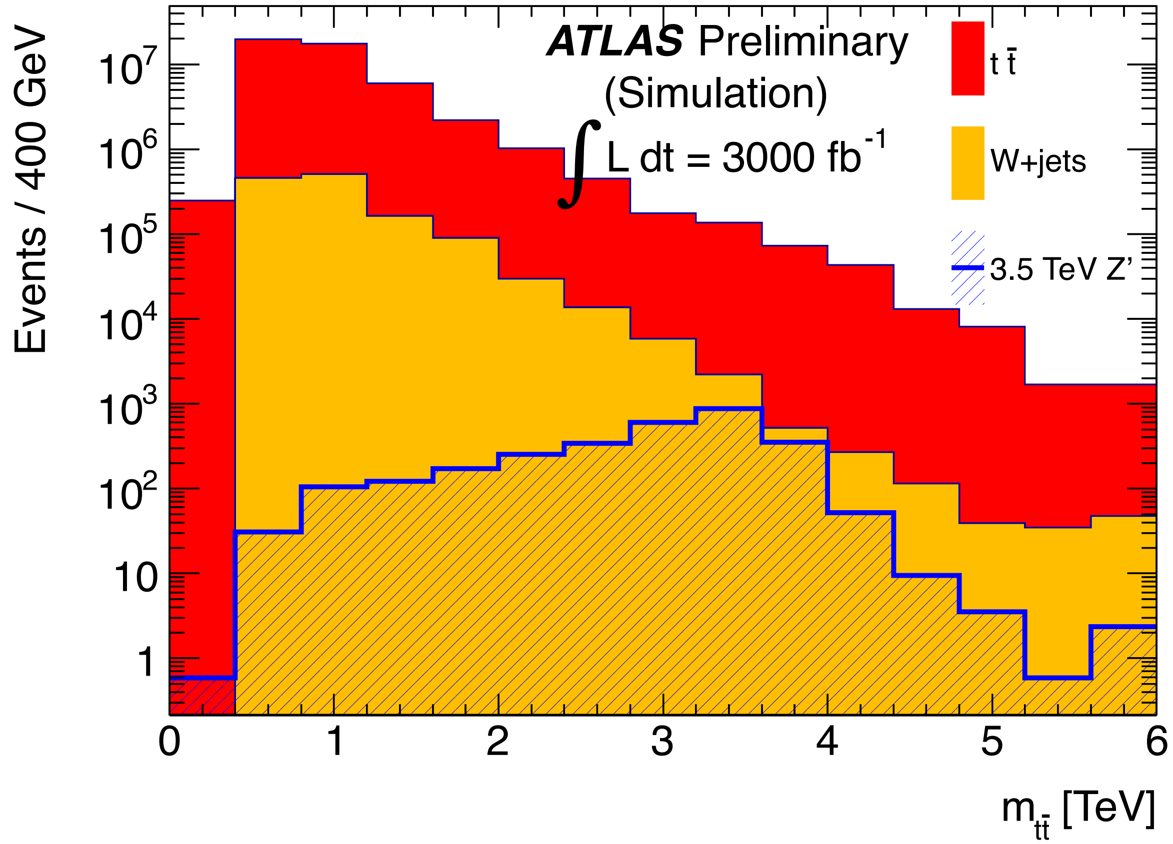
New Physics with tops

Studies of ttbar resonances at high-luminosity LHC

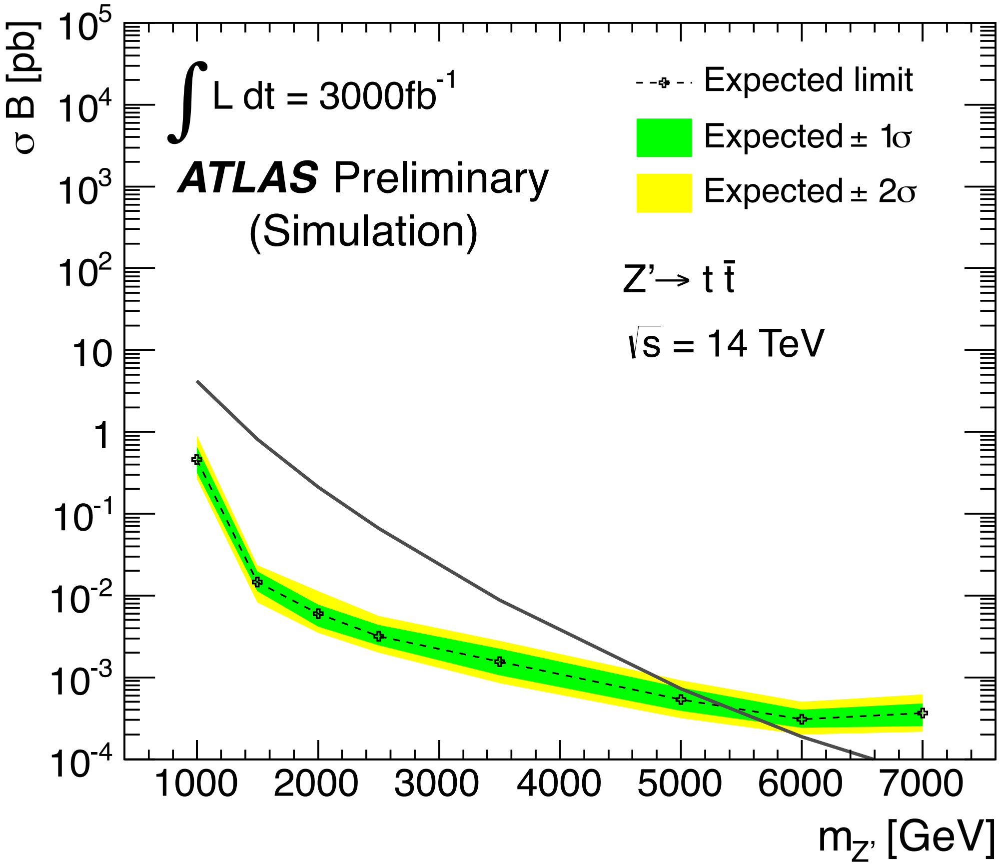
- Goal:
  - *Understand sensitivity to non-SM physics with simple, parameterized object reconstruction*
  - *At 14 TeV with 300/fb, 1000/fb, and 3000/fb*

C. Polland, A. Kotwall

Reconstructed ttbar mass spectrum



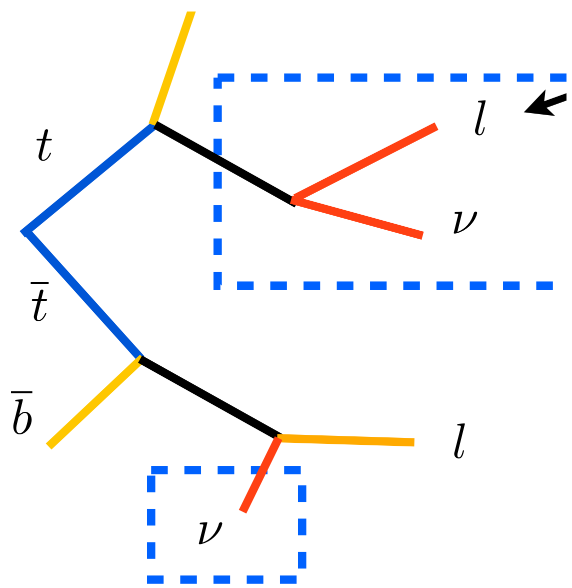
Expected KKgluon mass limit

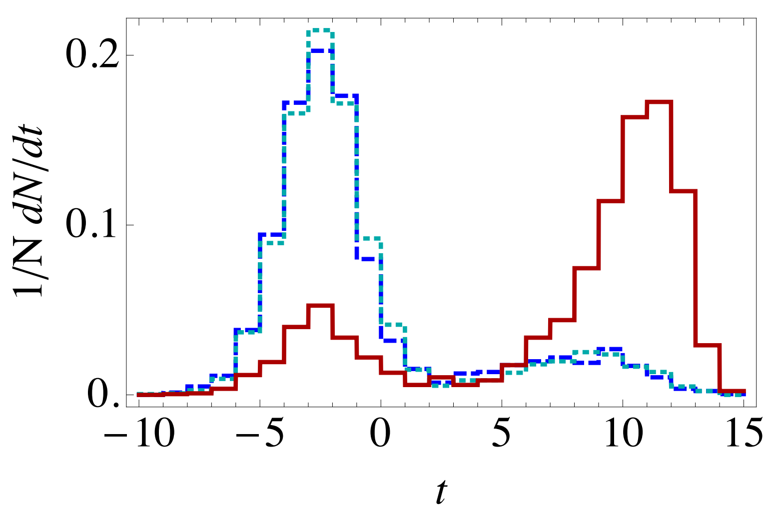


model	$300\,\text{fb}^{-1}$	$1000\,\text{fb}^{-1}$	$3000\,\text{fb}^{-1}$
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
$Z'_{\text{Topcolour}}$	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)

New variables to search for new physics in top-like events

Optimal variables for variants of stop searches were discussed in a number of talks. Mostly in the context of LHC, but should be applicable in a broader context.





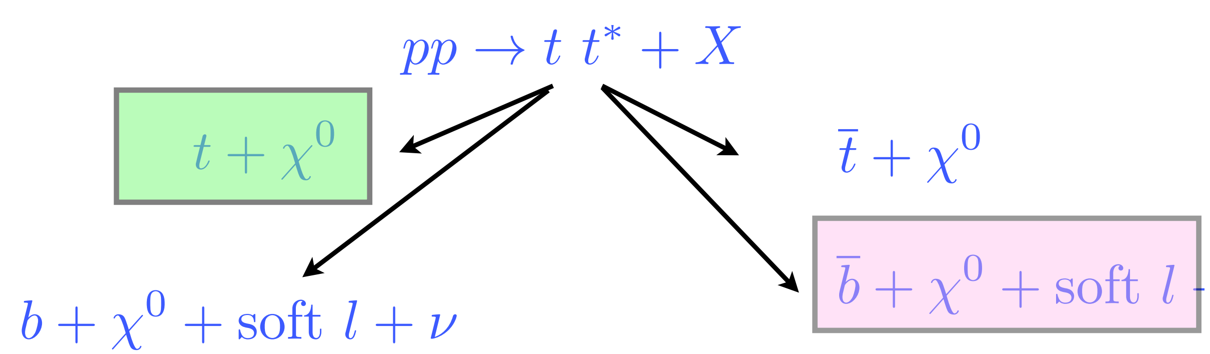
$\sqrt{s} = 8$ TeV , $\mathcal{L} = 20$ fb $^{-1}$

	σ_{sig}	$\sigma_{t\bar{t}}$	σ_{tW}	S/B	σ
preselection	2.1	54	4.3	0.036	1.2
lepton veto	2.1	44	3.4	0.044	1.3
$b_1\ p_T > 125$	1.5	22	1.6	0.065	1.4
$r_{pT} > -0.2$	1.5	21	1.5	0.066	1.4
$C < 3.0$	1.4	18	1.3	0.072	1.4
$t > 9.0$	0.98	0.82	0.38	0.82	3.5

big jump

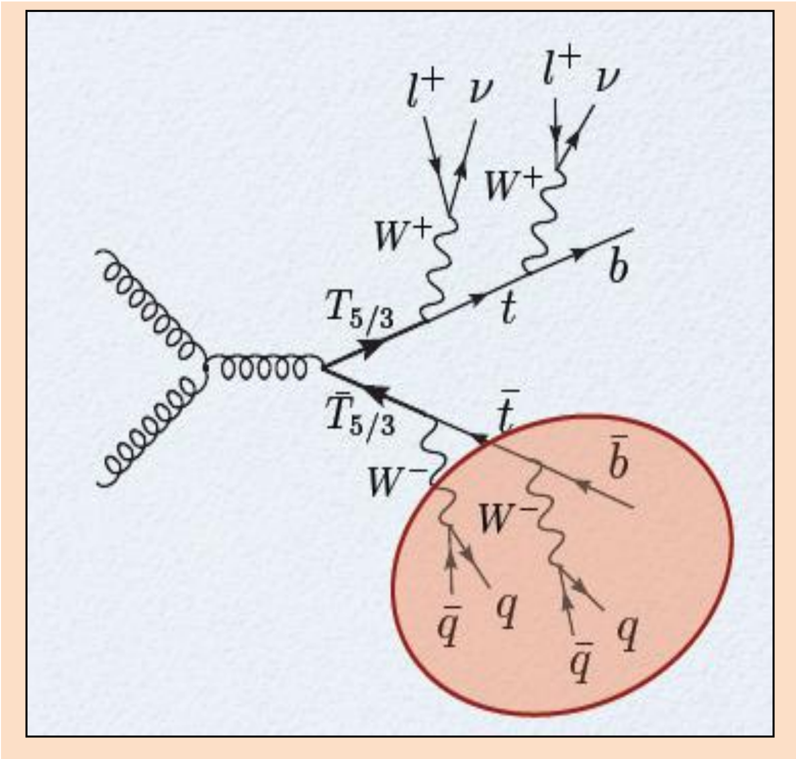
topness

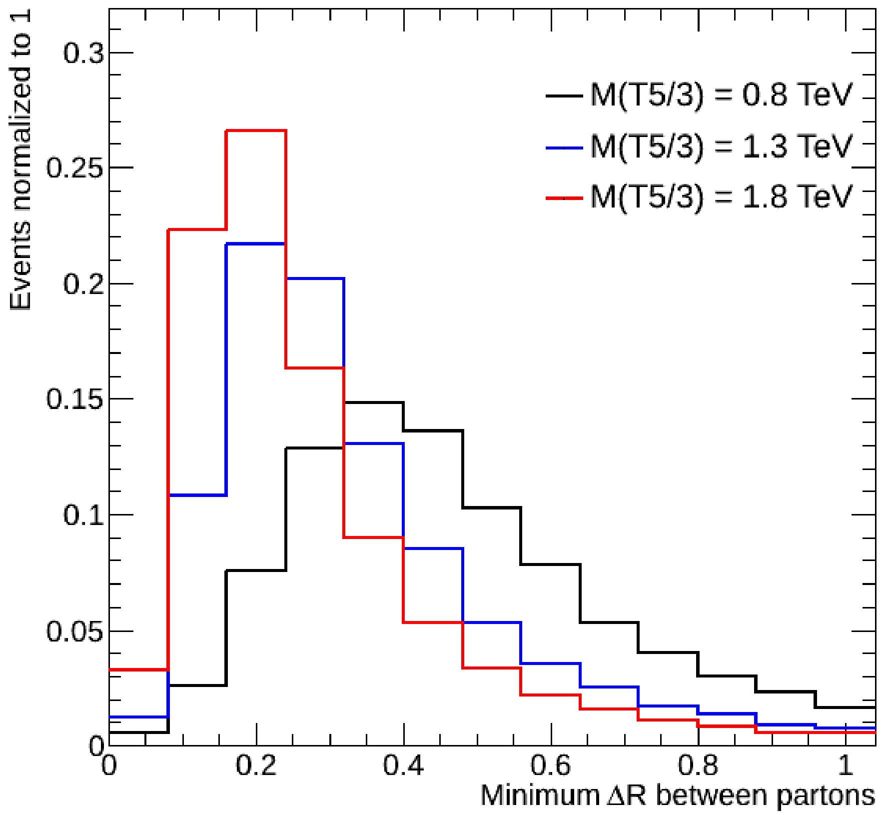
$$m_{\tilde{t}} = 500 \text{ GeV}$$
$$m_\chi = 200\text{GeV}$$
$$BR(tb + \not{E}_T) = 50\%$$



M. Graesser

Search for exotic top partners with charge 5/3





A. Avetysian

- First look at top partner with charge 5e/3 at 33 TeV and 13 TeV
- Search is feasible
- Next steps:
  - Finalize Delphes parametrization
    - Pileup subtraction will be improved
  - Jet substructure in Delphes
  - Generate same-sign backgrounds

Kinematics of top-like final states

Top quark kinematics : cross-section at NNLO

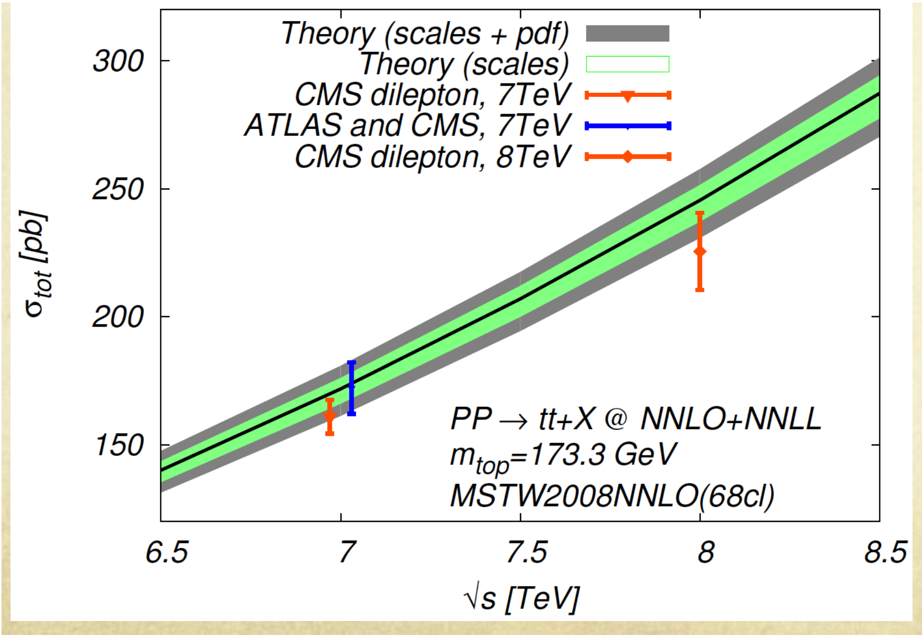
NNLO phenomenology at the LHC:

Czakon, Fiedler, Mitov '13

✓ New NNLO corrections from gg-reaction are large: as large as the ones due to the Coulomb-threshold approximation

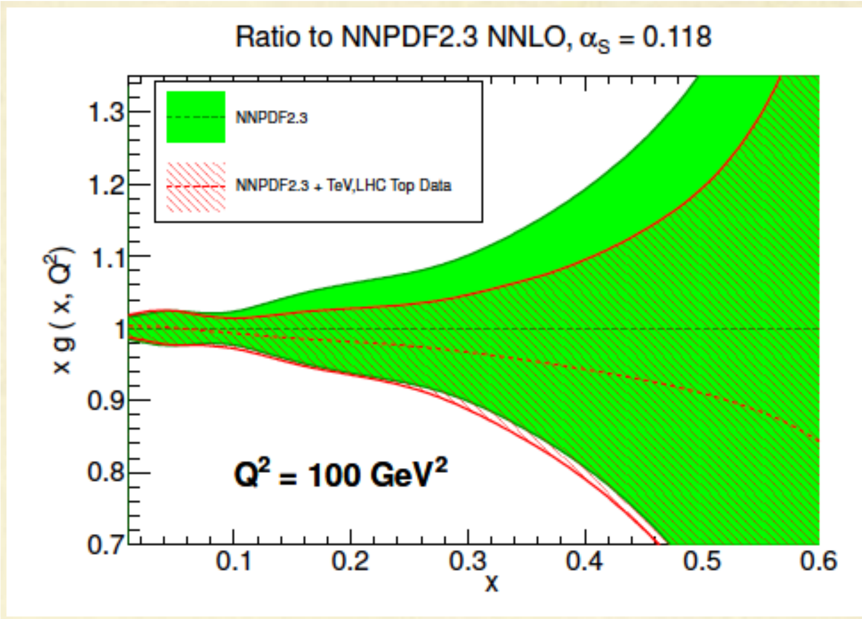
✓ At most 6% scale +pdf uncertainty

✓ Good agreement with LHC measurements

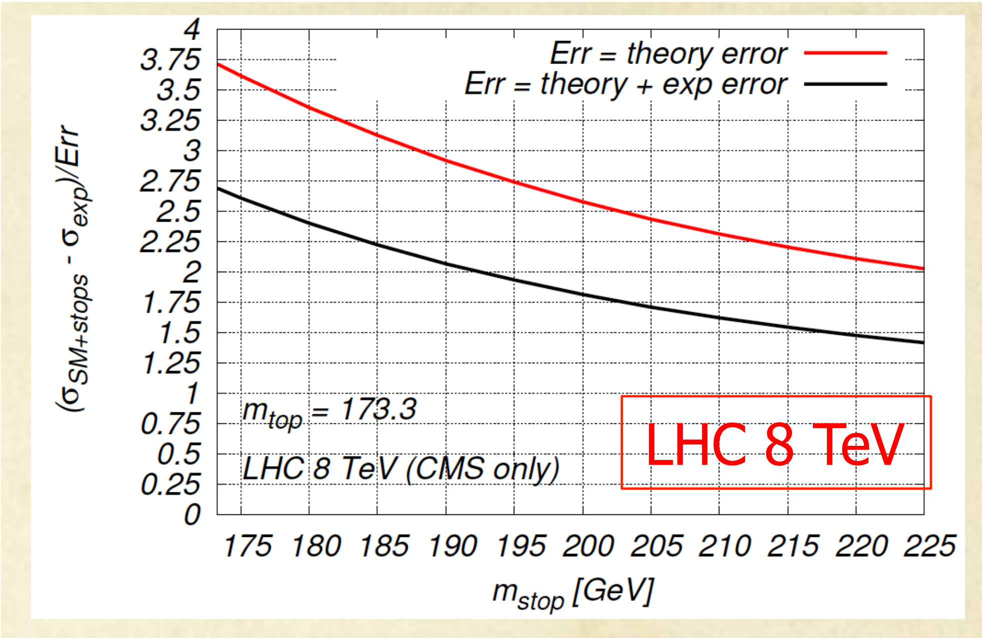


✓ We have reached a point of saturation: uncertainties due to

- ✓ scales (i.e. missing yet-higher order corrections) ~ 3%
- ✓ pdf (at 68%cl) ~ 2-3%
- ✓ alpha_s (parametric) ~ 1.5%
- ✓ m_top (parametric) ~ 3%



A. Mitov



Exclusion of stealthy stops from the cross-section

Top quark forward-backward asymmetry:

The asymmetry is an obvious elephant in the room

The asymmetry is seen almost everywhere, in top-related and in lepton-related observables

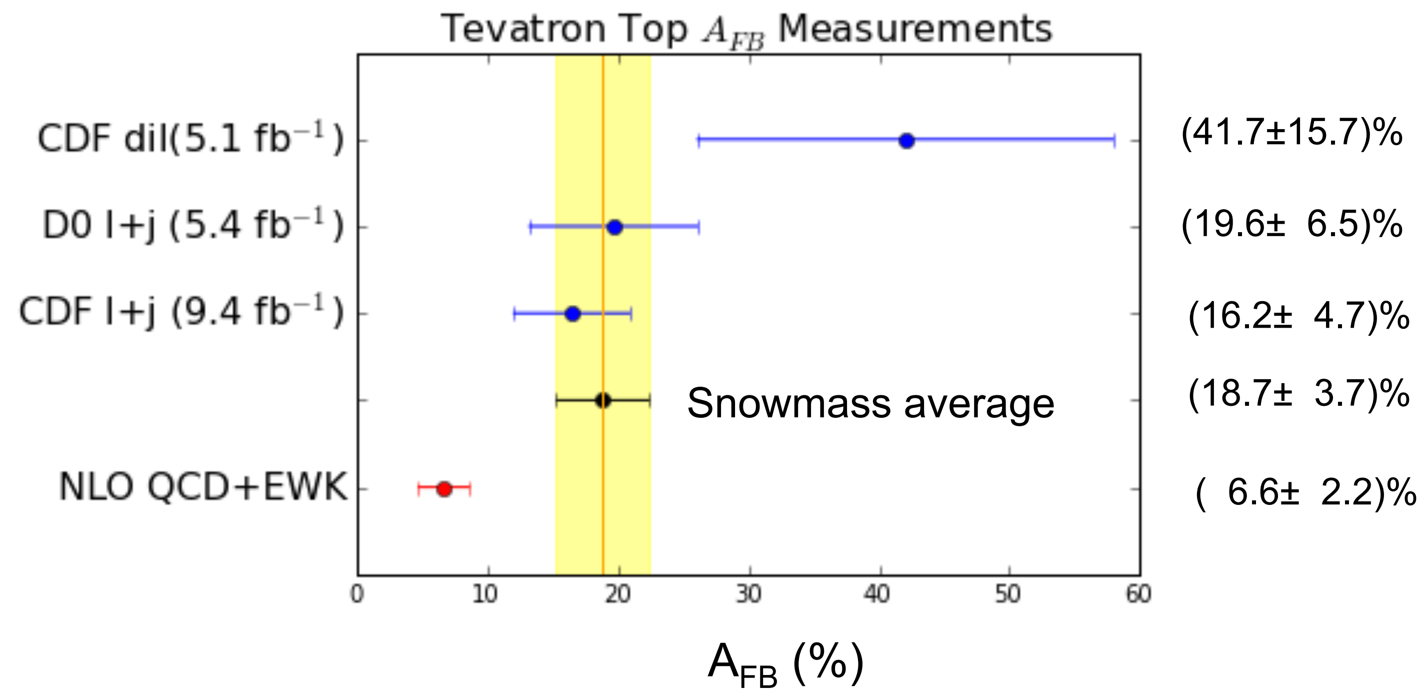
CDF analysis points towards a single Legendre moment that causes the asymmetry

Seems that ``complete profiling'' of $q\bar{q} \to t\bar{t}$ is possible (model-independent predictions for the LHC !)

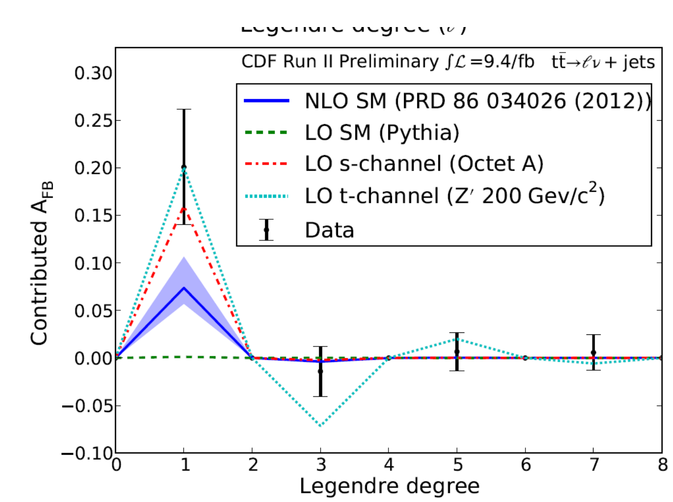
Understanding SM prediction for the asymmetry is crucial; progress with NNLO is encouraging since it will get extended to kinematic distributions as well. Sooner or later the NNLO asymmetry will be known.

Excessive contributions to the asymmetry appear to be (roughly) independent of the transverse momentum of the top pair -- short distance origin of the excess ?

Interesting to measure the asymmetry in other ways; for example LHCb can do such measurements



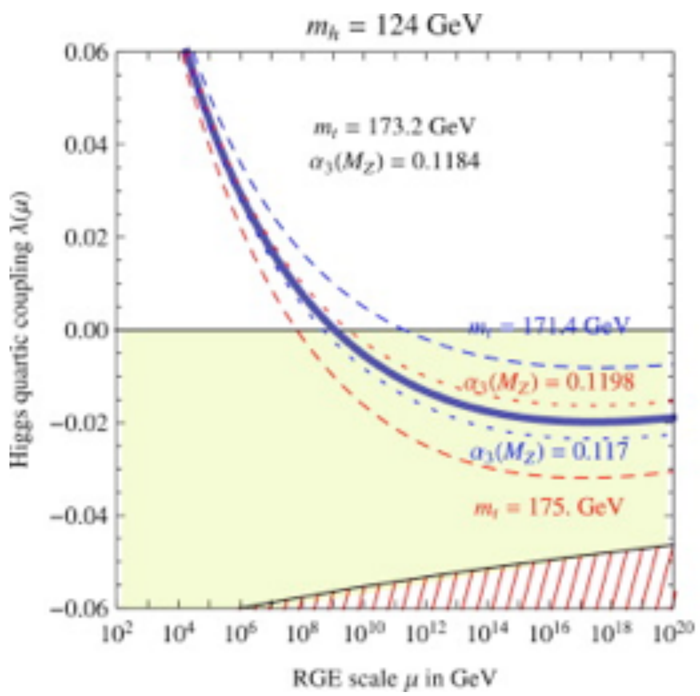
- contribution of moments to A_{fb}
  - independent asymmtries add!
  - A_{FB} is entirely due to linear term

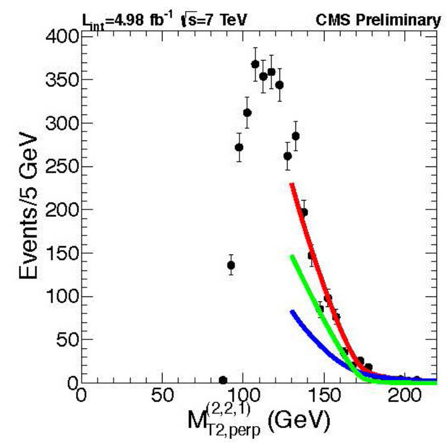


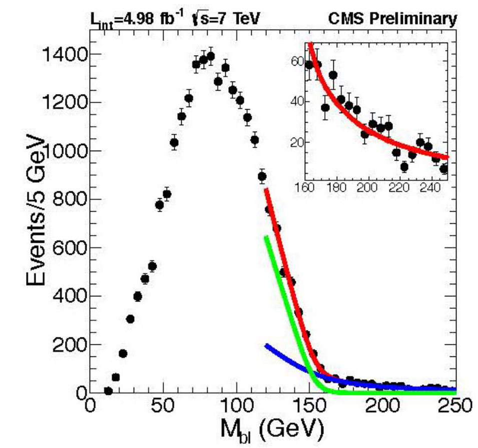
D. Amidei

The fate of the Universe, a.k.a. ``the top quark mass problem”

Top quark mass at CMS







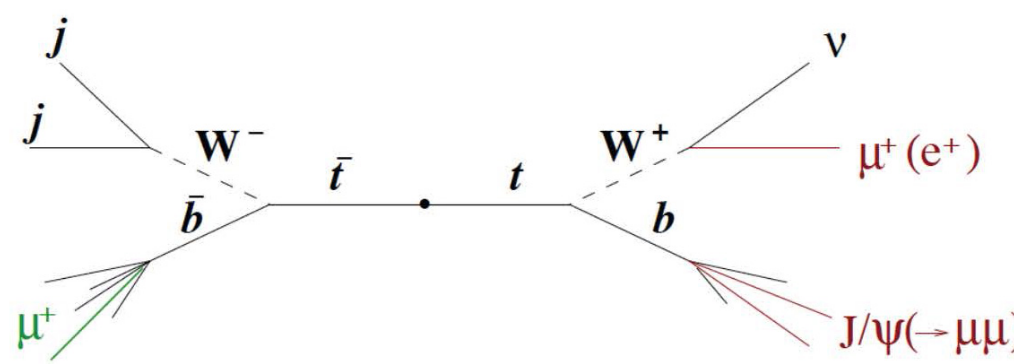
CMS analytic implementation avoids use of MC calibration
➔ systematics uncertainties partially uncorrelated with standard analyses

$m_t = 173.9 \pm 0.9\ (\text{stat.})\ ^{+1.2}_{-1.8}\ (\text{syst.})$ GeV

Paper in preparation

Correlations with standard dilepton analysis under study
(preparation for inclusion in new CMS combination)

New set of measurements at the CMS seems to be more theoretically transparent -- we may actually know what we are measuring ! This is very impressive; it suggest that LHC experiments will do better than expected in top quark mass determination, both nominally and at the conceptual level



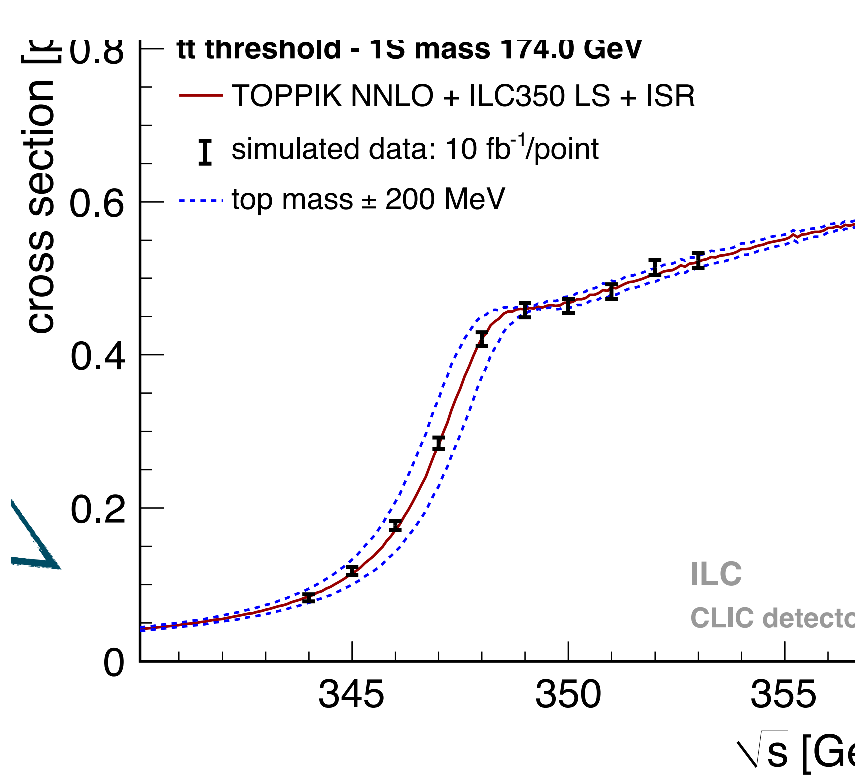
S.Wimpenny

Linear collider top threshold

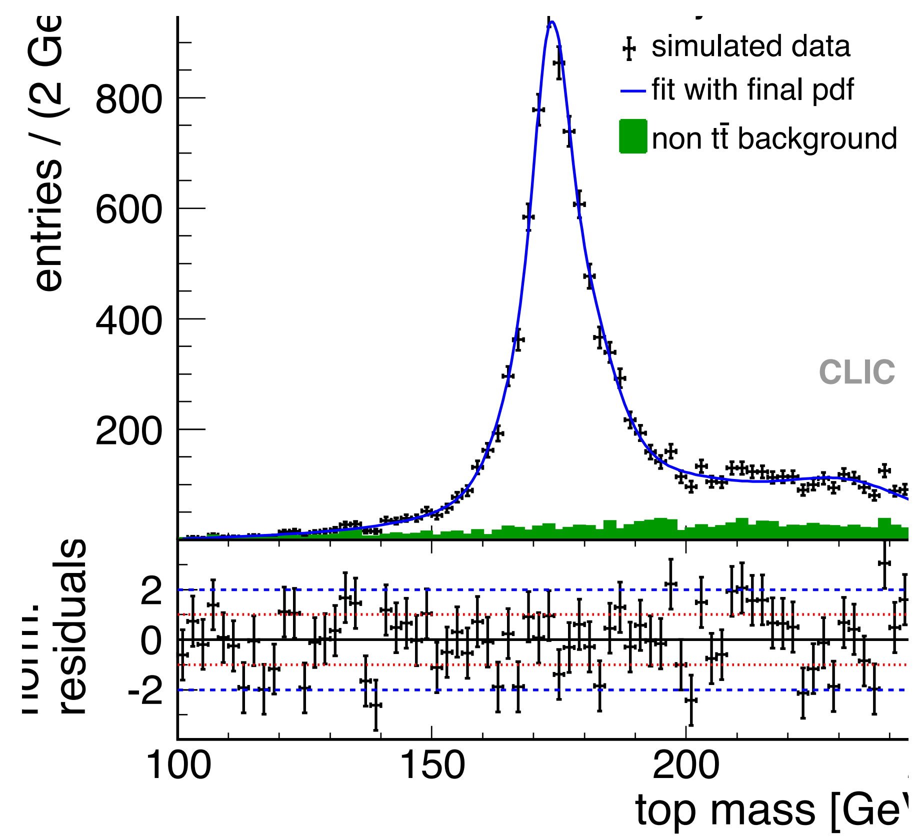
N^3LO results for top quark threshold production cross-section will become available soon. Big improvement for top mass, top width and strong coupling from the top threshold scan

$$R_{\rm res} = {\rm R}_{\rm res}^{\rm LO}\left[1 - 6.695\alpha_s + (-71.620\ln\alpha_s + 82.659)\,\alpha_s^2 + (-16.352\ln^2\alpha_s - 0.379\ln\alpha_s - 7x.xxx)\,\alpha_s^3\right]$$

A. Penin



F. Simon



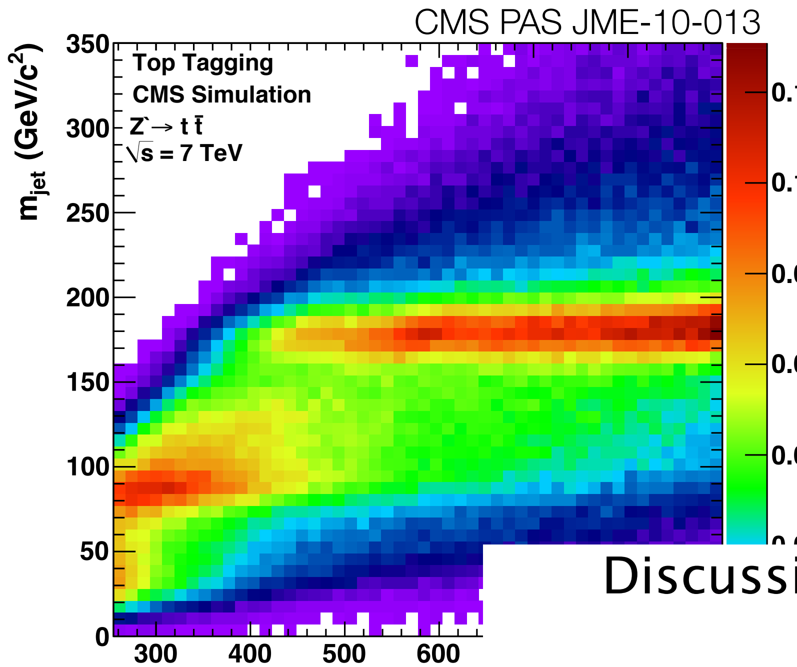
1S top mass and α_s combined 2D fit	
m_t stat. error	27 MeV
m_t theory syst. (1%/3%)	5 MeV / 9 MeV
α_s stat. error	0.0008
α_s theory syst. (1%/3%)	0.0007 / 0.0022

channel	$m_{\rm top}$	$\Delta m_{\rm top}$	$\Gamma_{\rm top}$	$\Delta\Gamma_{\rm top}$
fully-hadronic	174.049	0.099	1.47	0.27
semi-leptonic	174.293	0.137	1.70	0.40
combined	174.133	0.080	1.55	0.22

Top detection

Top detection and algorithms

- As collision energies increase, particles are produced with higher p_T
  - Boosted regime
- To maintain efficiency for selecting certain physics processes, new techniques required
  - Jet substructure
  - Used for reconstruction of boosted W, Z, H bosons, top quarks
- How well can we reconstruct such objects?
- Can we maintain this reconstruction going to higher energies?
  - What about pileup?
- Where do the current methods break down and what are the next steps?



Discussion of Potential Systematic Errors

Experimental only - For theory errors see e.g. Vos

- Luminosity: Critical for cross section measurements
  Expected precision 0.1% @ 500 GeV

- Beam polarisation: Critical for asymmetry measurements
  Expected to be known to 0.1% for e- beam and 0.35% for e+ beam

- Migrations/Ambiguities: Critical for AFB:
  Need further studies but expect to control them better than the theoretical error

- Jet energy scale: Critical for top mass determination
  Systematic study CLIC states systematic error ~ statistical error

- Other effects: B-tagging, passive material etc.
  LEP claims 0.2% error on R_b -> guiding line for LC

S. Chekanov, J. Dolen, J. Pilot, R.Poeschl, B. Tweedie

Activities: what we are focusing on

- Top quark mass
- Top quark couplings
- Kinematics of top quark final states
- New Physics in events with top quarks
- Rare decays
- Top detection strategies and algorithms

Sample projects for Snowmass studies

Limitations of the top quark mass measurements at hadron colliders, including the high-luminosity LHC -- are there any?

Ultimate precision of top quark coupling measurements at HCs and LC for ttZ, ttgamma, ttH, ttgluon. Implications for BSM physics

Robustness of existing top-taggers under extreme conditions (very high pile-up, very high energy) for LHC14, LHC33 and VLHC. Use physics benchmarks from NP group

Reach of hadron colliders (LHC and higher energy) and the ILC for flavor-changing top decays and direct measurements of Vts, Vtd

Searches for stealthy stops -- hadron collider reach, LC reach

Discovery strategies and studies of top partners at various colliders

The plan to move forward

- Identified contacts for each of the working groups and conveners in charge of particular working groups
- Produced documents that summarize our current knowledge of top quark physics and identified things to study/address in the near future
- Topical groups will work on projects and white papers; the plan is to have rough drafts in place by early June
- Whenever possible, aim at a clear comparison of physics at different machines using simple metric (e.g. coupling's precision vs. collider type, mass precision vs. collider type; particular new physics reach vs. collider type)

Things that we worry about

- There is nothing seriously controversial about the Snowmass process in the top quark working group so far.
- However, there is a general sentiment that there is not enough time for this process to produce in-depth studies
- Most of the studies reported/discussed are focused on the LHC . High-luminosity LHC, 33 TeV LHC and even higher-energy hadron collider are rarely discussed.
- No independent studies of the ILC physics will (most likely) be happening ; most of the results that tend to be used are from the ILC R&D reports

Conclusions

- The top quark working group had a rather interesting meeting, at least I expected something much less exciting
- However, interesting things (for me, admittedly) were not related to ``physics of Snowmass" process and not (directly) related to the conclusions that we should reach by the end of it
- I feel that there is a danger to sail through these meetings in the mode of ``a physics conference" while these meetings should not - by their nature -- be conference-like.
- We tried to keep this in mind when organizing discussions in the top group, but I do not know if we succeeded.
- We need to have more discussions in groups and between groups
- We do have a plan on how to move forward that fits into the time frame given to us by M.P. and Ch.B. and we will try our best to pursue it